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METHOD FOR MEASURING THE LINEAR DENSITY OF ELECTRONS AND THE DIFFUSION COEFFICIENT WITH THE AID OF INTERMEDIATE-TYPE METEOR RADIOECHOES

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SUMMARY

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A new method is proposed for the measurement of linear density of electrons in an ionized meteor trail by the shape of radioechoes of intermediate type trails. Described also is the measurement method of the diffusion coefficient in the meteor zone region, based upon the accounting of the duration and analysis of the shape of meteor radioechoes from intermediate-type trails.

Author

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In order to estimate certain parameters of meteor bodies, it is necessary to determine the linear electron density α in an ionized meteor trail. This refers, for instance, to the estimate of meteor body mass, to the construction of the distribution law of meteor bodies by masses, and so forth. The latter can be found from the statistical characteristics of meteor radioechoes. It is well known [1, 2], that in the case of unsteady type trails (also called underdensified or unsaturated) the initial amplitude of an echo-signal is proportional to the first power of linear density of electrons: $U_m \sim \alpha$. As to the duration of the reflection (having an exponential form), counted on the level U_m / e, it is not dependent on α. But in the case of steady-type trails (also called overdensified or saturated), the duration of the meteor radioecho is proportional to the

* METOD IZMERENIYA LINEYNOY PLOTNOSTI ELEKTRONOV I KOEFFITSIENTA DIFFUZII S ISPOL'ZOVANIYEM METEORNYKH RADIOEKHO PROMEZHUTOCHNOGO TIPA.

the first power of α: $\tau \sim \alpha$ (see [1, 2]. The dependence of the reflection amplitude on α is quite weak: $U_m \sim \alpha^{1/4}$ [1, 2].

That is why the distribution of meteor bodies by masses are usually found from amplitude distribution of unsteady-type meteor radioechoes, or from the distribution of steady-type meteor radioecho durations.

There exist also other possibilities of investigating the distribution of masses of meteor bodies: by the distribution of heights [3, 4], by the distribution of durations of meteor radioechoes from unsteady-type trails (at threshold level) [5, 6], and others. However, in all these methods, the trails of the intermediate type are not only not utilized but excluded from the consideration, for in the opposite case, the results of measurements would be found erroneous. At the same time, the utilization of radioechoes from trails of intermediate type (with linear electron density in the interval $\alpha \approx 10^{12} \div 10^{13}$ electron/cm) would be quite desirable. It should be stated, first of all, that in the study of a given meteor stream (or of sporadic meteors in a certain narrow interval of meteor body velocities), a quite substantial interval of masses is excluded from consideration (in $2 \div 3$ stellar magnitudes).

Moreover, although the study of the statistical characteristics of meteor masses by the statistical characteristics of unsteady (exponential) radioechoes is quite promising, it is, however, then necessary to know the shape of antenna radiation pattern ; but the radiation pattern of the antenna system of a meteor radar may be found to be known quite inaccurately. Besides, resonance effects should be taken into account.

The statistical characteristics of reflections from steady-type trails are broadly utilized for the transition to the statistical characteristics of meteor bodies. However, in that case, crushing of meteor bodies in the terrestrial atmosphere, the deionization processes, etc. should then be taken into account. But the role of the crushing process at formation of steady-type trails (little intense, however,) is still at the stage of clarification.

In the region of intermediate-type trails, the effect of the crushing process of a meteor body, of deionization, and also of destruction of the trail by vortices is significantly weaker than in the region of steady trails.

During location of intermediate-type trails, the resonance effects are manifest more seldom and in a less intense fashion than in the case of unsteady trails. This is why one may anticipate, that measurements of linear density of electrons (and the subsequent transition to meteor body parameters) will be conducted in better conditions with the use of intermediate-type trails, than during utilization of steady and unsetady types in the presence of a sufficiently fully developed theory of radiowave scattering on intermediate-type trails.

As far as we know, trails of intermediate type were not utilized during measurements of α at the point of normal scattering of radiowaves by the meteor trail [1 – 4] and, consequently, they were also excluded from the consideration during studies of mass distribution of meteor bodies. This is apparently explained by quite complex a dependence on of thr amplitude U_m as well as on the duration τ of reflection from the ionized meteor trail with $\alpha \approx 10^{12} \div 10^{13}$, and also by the absence of of formulas providing the dependences $U_m(\alpha)$ and $\tau(\alpha)$.

At the same time, if the amplitude of reflection in case of an unsteady trail depends sharply on α, and in case of a steady one — the duration, the pattern of reflection depends strongly on the linear density of electrons in case of trails of intermediate type. The pattern of unsteady radioechoes is exponential (independently from α), and that if steady radioechoes is almost rectangular (and it practically does not depend on α). The pattern of transitional-type radioecho varies from "nearly-exponential" to "nearly-rectangular", depending upon the magnitude of α, (see Fig. 1). This precisely gives the possibility to estimate or to measure the value of linear electron density in the trail. The analytical dependence of echo-signal's instantaneous amplitude on time (taking into account the wavelength λ and the diffusion coefficient D) for the given value of α, was obtained by Kaiser and Closs [1]. Plotted in Fig. 1 is the family of curves for $\alpha = 10^{12}, 3 \cdot 10^{12}, 5 \cdot 10^{12}$ and 10^{13} electrons/cm [1, 2]. Comparing the shapes of the theoretical curves' family with the envelope of the amplitude-temporal pattern of the registered echo-signal (Fig. 2), we may estimate the value of α. However, such a method is quite rough, and moreover it is little practicable. To increase the measurement precision of α,

and to simplify the practical realization of this possibility, it is appropriate to estimate the pattern of the radioecho (from an intermediate trail) by any parameter and relate this parameter with the linear density of electrons.

1. - Coefficient of Meteor Radioecho Pattern. It seems useful to estimate the pattern of a meteor radioecho by a "coefficient of pattern" (note that there is question of the envelope of all pulses reflected from the given trail, rather than of a single pulse). This coefficient could be determined by various mathods. Apparently, the most characteristic one is the correlation between durations of " summit" and "drop" of reflection (Fig. 3a). This is why we shall determine the duration of reflection at a certain, sufficiently high level, U_1 (τ_B), and the duration of the "drop" between two levels U_1 and U_2 (τ_c).

We shall understand by "coefficient of pattern" the drop to summit duration ratio $K_\Phi = \tau_c / \tau_B$. Thus, the smaller the value of K_Φ, the closer is the reflection pattern to rectangular, and, to the contrary, the greater K_Φ, the closer the pulse envelope to the exponential. In other words, the trail of intermediate type approaches the steady type as K_Φ decreases, and the unsteady one as it increases.

The choice of calculation levels U_1 and U_2 is quite essential, for this will depend to a significant extent upon the precision in the determination of α. Evidently, the level U_2 must not be too near U_m; it is obvious also that both levels, U_1 and U_2, must correspond to the segment of the dropping curve with a sufficient steepness. It appears appropriate to select the calculation levels $U_1 = 0.8\, U_m$ and $U_2 = 0.5\, U_m$ We shall not dwell here upon more detailed selection of levels.

2. - Dependence of the coefficient of pattern K on the linear electron density. - Let us find the dependence of the coefficient of pattern K_Φ on the linear electron density α for the family of theoretical curves [1, 2] [Fig. 1). Plotted along the vertical axis of Fig. 1 is the reflection factor g, proportional to the amplitude of reflected signals ($U \sim g$), and along the horizontal axis, the quantity t^*, proportional to the time t.

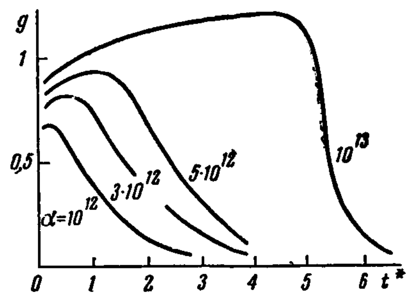

Fig. 1

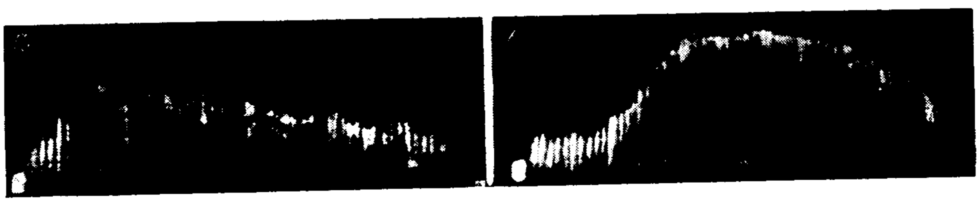

Fig. 2

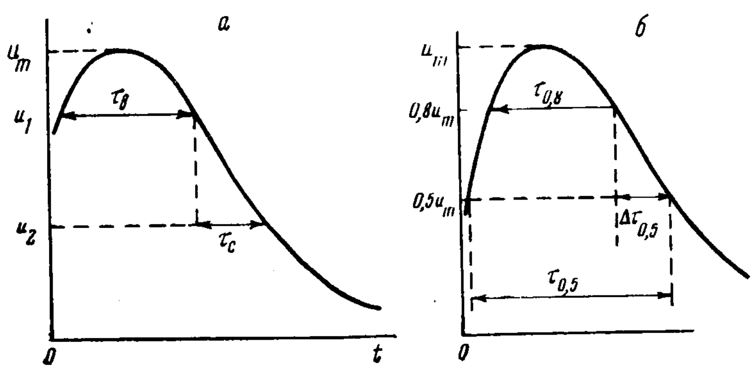

Fig. 3

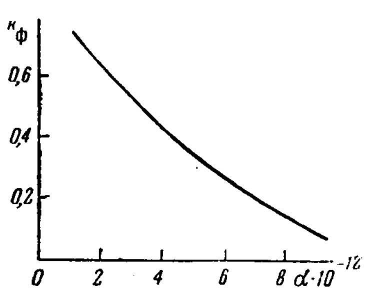

Fig. 4

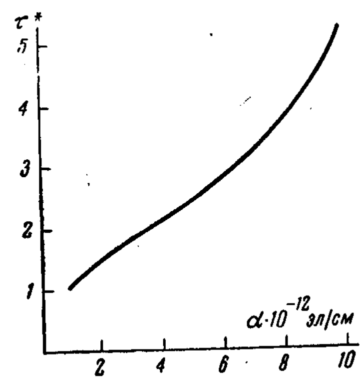

Fig. 5

$$t' = 4k^2 Dt \qquad (k = 2\pi/\lambda),$$

where λ is the wavelength, D is the diffusion coefficient. The coefficient of pattern for each curve (corresponding to the given α) will be determined as the ratio τ_c^* (counted between the levels $U_1 = 0.8\,U_m$ and $U_2 = 0.5\,U_m$), and τ_B^* (counted at the level $U_1 = 0.8\,U_m$). We have

$$K_\Phi = \tau_c^* / \tau_B^*,$$

since [1]

$$\tau_c^* / \tau_B^* = \tau_c / \tau_B.$$

Note that the value of the greatest amplitude of reflection U_m corresponds to the given value of α.

The dependence $K_\Phi = f(\alpha)$ is plotted in Fig. 4. Note that for the exponential the coefficient of pattern is $K_\Phi = 2.1$.

Thus, the method of linear density of electrons, α, measurement by the trails of intermediate type consists in the following.

1.- From the amplitude-temporal registration of the meteor radioecho (Fig. 2) we find the duration of "summit" τ_B at level $0.8\,U_m$ and the duration of "drop" τ_c between levels $0.8\,U_m$ and $0.5\,U_m$ (Fig. 3). At the same time, it is necessary to account for the amplitude characteristic of the receiver-indicator loop (circuit).

2.- We find the coefficient of pattern of the registered meteor radioecho of intermediate type

$$K_\Phi = \tau_c / \tau_B \qquad (3)$$

3.- By the graph of Fig. 4, providing the theoretical dependence of the coefficient of pattern $K_\Phi = \tau_c^* / \tau_B^*$ on the linear electron density, we find the value of α, corresponding to the experimental value of K_Φ.

Omitting here the statistical results of observation analysis, we shall bring forth for the sake of illustration an example of determination of α for a trail of intermediate type observed during the time of action of Gemini 1963 shower. We plotted in Fig. 2 a the amplitude-temporal registration of the reflection observed at $\lambda = 9.59$ (st."Tripol'ye" of Kiyev State University) on 14 Dec.1963 at Oh. 00 m. 35 sec.local time).

The durations τ_c and τ_B, taking into account the amplitude characteristics of the receiving-indicator circuit, were found to be as follows: $\tau_B \approx 0.043$ sec, $\tau_c \approx 0.025$ sec. The coefficient of pattern is $K_\Phi \approx 0.58$. As follows from Fig. 4, $\alpha \approx 2.5 \cdot 10^{12}$ electrons/cm.

Another intermediate trail was registered at 0 h 5 min, 29 sec (Fig. 2). To it correspond $\tau_B \approx 0.028$ sec and $\tau_c \approx 0.02$ sec. The coefficients of pattern are in this case $K_\Phi \approx 0.71$; consequently $\alpha \approx 1.3 \cdot 10^{12}$ electrons/cm.

Aside from measuring α, it is of interest to consider the possibility of measuring the diffusion coefficient by observation of intermediate-type trails.

3. - On the possibility of measuring the diffusion coefficient by ionized meteor trails of intermediate type. As is well known, the diffusion coefficient in the meteor zone region can be measured by the duration of exponential-pattern radioecho (from unsteady-type trails). The basis of this method is constituted by the expression for the duration τ of a meteor radioecho from an unsteady trail, (with linear electron density $\alpha \ll 10^{12}$ electrons/cm) at the level U_m/e, where U_m is the greatest initial value of the amplitude of the echo-signal), obtained by Kaiser and Closs [1, 2] :

$$\tau = \frac{\lambda^2}{16\pi^2 D} , \tag{4}$$

where λ is the wavelength.

Upon measuring the duration τ of reflection at level U_m/e, and knowing λ, we find the diffusion coefficient D:

$$D = \frac{\lambda^2}{16\pi^2 \tau} . \tag{5}$$

This measurement method of the diffusion coefficient, proposed by Greenhow [7], was subsequently developed and successfully applied by a series of researchers [7 - 9].

However, at relatively rather low a potential and sensitivity of the radar device, the quantity of registered trails of unsteady type providing clear amplitude-temporal patterns, is not considerable. Moreover, the polarization effects, intensively manifest in the region of unsteady trails, complicate the analysis of the results of observations or induce substantial errors in the measurement of the diffusion coefficient [10, 11].

In connection with this it appears to be interesting to clarify the possibility of utilizing the intermediate-type trails for the measurement of the diffusion coefficient. Essential is also the fact, that the amplitudes of intermediate-type meteor radioechoes are, as a rule, substantially greater than the amplitudes of exponential radioechoes, which, in the presence of interferences and noises, allow to improve the precision of some measurements.

The principal considerations relative to utilization of radioechoes from intermediate-type trails for the measurement of the diffusion coefficient consist in the following.

The reflection duration τ, counted at a specific level (relative to the greatest value of radioecho amplitude), depends on the linear electron density α and on the diffusion coefficient, just as in case of steady-type trails (see Fig. 1) [1, 2]. But, contrary to the radioecho of the steady type, the obvious and at the same time the simplest analytical dependence τ on D and α is absent for that of the intermediate type. However, having determined the value of linear electron density α in the given trail, measured the duration τ of reflection at the specified level , and found for the corresponding theoretical curve the value of the abscissa for the same level, it would be possible to determine the value of the diffusion coefficient (see Fig. 1).

4. - <u>Duration of reflection from an intermediate-type trail. Determination of the diffusion coefficient by reflection from intermediate-type trails</u>. Because the radioecho from an intermediate-type trail may have a pattern substantially different from the rectangular, the duration τ of the radioecho for given D, and α depends essentially on the count level. Bearing in mind the decrease in measurement error, it is convenient to

count the duration of reflection at the level 0.5 from the greatest value of radioecho signal amplitude (see Figs. 1 and 3). We shall denote this duration by $\tau_{0.5}$ (Fig. 3 б). The family of theoretical curves, brought up in Fig. 1, was constructed as a function of the quantity $4k^2 Dt$, where $k = 2\pi/\lambda$. Let us designate

$$\tau^* = 4k^2 D\tau \qquad (6)$$

as the reduced reflection duration. This quantity τ^* will be function of α (see Fig. 1) and it can be represented in the form of a graph (Fig. 5).

Therefore, if the reflection duration at level 0.5 ($\tau_{0.5}$) is known to us from experiment, we may, upon preliminary determination of α, find from Fig. 5 the reduced duration $\tau_{0.5}^*$ corresponding to this value of α, and determine the diffusion coefficient D, which, as follows from (6), will be equal to

$$D = \frac{2\tau_{0.}^*}{16\pi^2\tau_{0.5}} \qquad (7)$$

Therefore, the method of measurement of the diffusion coefficient consists in the following.

From the amplitude-temporal registration of a meteor radioecho (taking into account the charcteristic of the receiving-indicator circuit) we find the duration of reflection at level 0.8 ($\tau_{0.8}$), the duration of reflection at level 0.5 ($\tau_{0.5}$), and the duration of the "drop" between the levels 0.8 and 0.5 ($\Delta\tau_{0.5}$). Subsequently, we determine the radioecho's coefficient of pattern (3)

$$K_{\phi} = \frac{\Delta\tau_{0.5}}{\tau_{0.8}} \qquad (8)$$

Further, we find the value of linear electron density α from the graph of Fig. 4. Having determined the reduced duration $\tau_{0.5}^*$, corresponding the found value of α (from the graph for $\tau_{0.5}^*(\alpha)$ in Fig. 5), we compute by formula (7) the value of the diffusion coefficient.

Note that the quantity $\tau_{0.5}^*$ is dimensionless. Substituting $\tau_{0.5}$ in seconds and the wavelength in meters, we shall obtain D in m^2/sec.

Omitting the statistical data on the diffusion coefficient, found by means of the above-expounded method, we shall limit ourselves to some examples.

5. - Example of measurement of the diffusion coefficient.- We shall illustrate the proposed method on the example of meteors observed in the Gemini 1963 epoch.

We brought out in Fig. 2 a the amplitude-temporal registration of the ionized meteor trail registered on 14 Dec.1963 at 0 h. 00 m. 35 s. Moscow legal time.

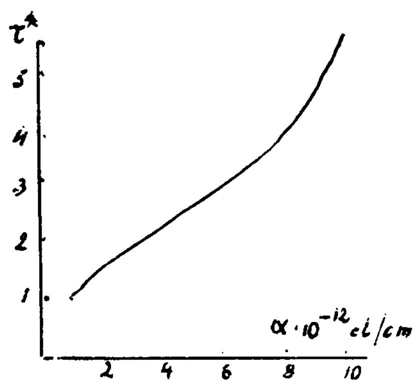

Fig. 5

The duration at level 0.5 from the greatest value of the amplitude U_m, taking into account the amplitude of receiver characteristic, will be $\tau_{0.5} \approx 0.09$ sec. The linear electron density (see above) is $\alpha \approx 2.5 \cdot 10^{12}$ electrons/cm. The corresponding reduced duration of reflection at level 0.5 (Fig. 5) is $\tau_{0.5}^* \approx 1.65$. And, finally, the diffusion coefficient will be found from the formula (7) :

$$D \approx \frac{(9.59\,m)^2}{16\ ^2} \cdot \frac{1.65}{0.09\,sec} \approx 10.7\ m^2/sec.$$

From the registration presented in Fig. 2 б, we find :

$$\tau_{0.5} \approx 0.048\ sec.,$$
$$\alpha \approx 1.3 \cdot 10^{12}.$$
$$\tau_{0.5}^* \approx 1.2.$$
$$D \approx 14.7\ m^2/sec.$$

6.- Questions relevant to subsequent development in connection with the utilization of intermediate-type trails for measuring α and D. In connection with the possibility of utilizing ionized meteor trails of intermediate type for the measurement ofelectron density and also of meteor body and atmosphere parameters, interest toward theoretical, methodical and applied questions, linked with radar location of intermediate-type trails is again aroused.

We shall mention some of the problems, the consideration of which constituting a specific interest. First of all the precision of the expounded method for measuring α and D by the shape of the radioecho from an intermediate-type trail should be carefully analyzed. To that effect we must in particular consider the effect on the pattern, amplitude and duration of reflection of initial radius, wavelength and polarization effects. This requires further development of the theory of radiowave scattering by intermediate-type trails, and also set up of experiments, including those on such type trail modeling. We should also take into account the correction for the finite time of trail formation (and not instantaneous), for, as a result of this effect the steepness of radioecho accretion will be less than would follow from the Kaiser and Closs theoretical curves for an infinitely extended diffusing trail.

Bearing in mind the subsequent transition from the linear electron density α to the mass of meteor bodies, we should ascertain the role of meteor body fragmentation process generating the trails of intermediate type.

It is necessary to compare the statistical data obtained from measurements of the diffusion coefficient with the utilization of usteady and intermediate-type trails.

Amongst relatively minor methodical questions, a careful choice of count levels, that would ensure least errors stemming from the undecipherability of the shape of the meteor radioecho envelope, is of interest.

And finally, utilizing the proposed method, we should obtain a sufficiently ample statistical material on the mass distribution of meteor bodies, that would complement the data obtained from the statistics of unsteady (exponential) and steady radioechoes.

In conclusion, I wish to express my gratitude to I.V.Braychenko, having supplied the data on amplitude-temporal registrations of meteor radioechoes of intermediate type, and to Yu. V. Chumak for his participation in their analysis.

***** THE END *****

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